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# Optimizing water usage through an automatic garden sprinkler system: Enhancing efficiency and sustainability in gardening

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ABSTRACT

This study investigates the design and operation of an automatic garden sprinkler system, focusing on the need for a dependable, self-operating watering solution that conserves water and supports night-time watering schedules. The research method included a detailed evaluation of the system's performance over 30 days, analyzing data on timing accuracy, water distribution efficiency, and user feedback. The results show that the system works accurately, starting watering cycles within minutes of the set time and efficiently distributing water evenly across the garden. The findings suggest the system can help reduce water waste, supporting global sustainability goals. Additionally, its flexibility and ease of use suggest it could be popular with gardeners and widely adopted. This research adds to the conversation on sustainable gardening and provides insights into using advanced technology in traditional gardening practices.



## 1. Introduction

This research paper examines automated garden maintenance, combining traditional gardening practices with modern technological advancements. It begins with a comprehensive literature review, tracing the evolution of irrigation from ancient methods such as the Shaduf and Qanat to modern automated sprinkler systems, highlighting human ingenuity over time. Modern irrigation systems have transformed agricultural practices by reducing dependence on erratic rainfall and enhancing yield stability, thus facilitating expansion in arid zones (Salazar and Rand, 2016; Powers and Lehmann, 2013). Traditional methods, such as village tank irrigation in Sri Lanka, continue to exemplify sustainable resource management (Abeywardana et al., 2019). The adoption of these technologies, often spurred by governmental policies and subsidies, particularly in regions like China, is aimed at overcoming economic and technical challenges (Cremades et al., 2015). However, despite technological advances, significant challenges remain, especially concerning the environmental impact of these systems in water-scarce areas (Zuidema et al., 2020). The development of irrigation systems has varied widely throughout history, from the extensive projects in ancient Egypt to communal systems such as the Acequias in New Mexico, illustrating the influence of legal and governance frameworks (Smith, 2022). In response to increasing water scarcity, initiatives such as the EU's Common Agricultural Policy promote environmentally efficient irrigation investments (Pérez-Blanco and Sapino, 2022). Moreover, the integration of smart irrigation technologies, which incorporate machine learning, is enhancing efficiency and addressing issues such as groundwater quality and climate change impacts (Letechipia et al., 2021; Abuzanouneh et al., 2022; Liu et al., 2018). This continuous evolution reflects a dynamic interplay of technological, environmental, and socio-economic factors, shaping agricultural practices globally. This paper delves into how these innovations in automated garden maintenance can contribute to sustainable and efficient gardening practices, highlighting the convergence of tradition and technology in nurturing the landscapes of tomorrow.

The transition from manual to automated garden sprinkler systems highlights a significant evolution in garden maintenance, marked by the integration of timers, sensors, and smart technologies. This shift to smart gardening emphasizes enhanced efficiency and responsiveness to environmental conditions. Smart irrigation systems, integral to Internet of Things (IoT) applications, play a crucial role in precision agriculture by providing scalable solutions

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for efficient water management (Yannopoulos et al., 2015). These technologies, including smart metering systems (Jin et al., 2019), improve the efficiency of garden sprinkler systems by accurately tracking water usage and optimizing irrigation schedules. Innovations like the replacement of traditional impact sprinklers with more energy-efficient spray sprinklers have reduced the energy requirements of irrigation machines (Robles et al., 2017). Additionally, the development of IoT-based systems for garden maintenance, including drone-aided thermal mapping for targeted irrigation (Jalajamony et al., 2023) and the integration of rainwater sensors to automate irrigation schedules (Li et al., 2019), reflects a shift towards automated, data-driven horticulture. Choudhari (2023) discussed the application of IoT in smart gardening systems, which can automate and optimize watering schedules based on real-time data, thereby improving the efficiency of automatic garden sprinkler systems. It reveals a transformative impact of technology on garden sprinkler systems, from historical water lifting devices to modern IoT integrations, paving the way for more sustainable and efficient gardening practices.

The critical impact of water wastage in conventional irrigation practices and the potential of automated sprinklers to enhance water conservation, particularly in the face of environmental sustainability, climate change, and water scarcity. Grafton et al. (2018) emphasized the paradox of irrigation efficiency, advocating for incentives that compel irrigators to consider return flows and maintain environmental flows, thereby reducing overall water consumption. This reflects the complex balance between economic needs and environmental conservation. Rosa et al. (2020a) highlighted the importance of sustainable irrigation practices that prevent the depletion of freshwater stocks and the loss of environmental flows, addressing global agricultural water scarcity. Jägermeyr et al. (2017) also discussed the need to secure environmental flow requirements to restore river ecosystems, even at the expense of reducing the water available for irrigation. Wada and Bierkens (2014) proposed innovative strategies in water management and governance to sustain global water use. Rosa et al. (2020b) defined sustainable irrigation practices as those that do not exceed renewable water availability or impair environmental flows. Sirimewan et al. (2020) emphasized the significance of sustainable water management in balancing environmental protection, social progress, and economic growth. It strongly supports the need for sustainable irrigation practices to tackle challenges related to water scarcity and environmental sustainability. The role of automated sprinklers in reducing water consumption is highlighted as crucial for optimizing water use in sustainable agricultural production amid growing climate and water-related pressures.

The economic analysis of garden sprinklers is pivotal for assessing the cost-effectiveness of various systems and evaluating the potential cost savings of automated sprinklers. Tambo et al. (2021) stressed the importance of economic considerations in the success of irrigation systems. Ağizan and Bayramoğlu (2021) provided a comparative investment analysis of different irrigation methods, including drip systems, highlighting differences in operating and investment costs crucial for informed system selection. Darouich et al. (2017) used a multi-criteria analysis to compare sprinkler and surface irrigation in wheat cultivation, focusing on water savings and economic returns, which offers insights into the economic implications of each irrigation strategy. Additionally, Zhang et al. (2019) discussed the economic benefits of using oscillating water flows in sprinkler systems, noting particularly the reduction in operation costs as energy prices rise. Morshed et al. (2021) conducted a cost-return analysis of rooftop and homestead gardening, demonstrating their economic viability with proper management. Morera et al. (2019) included additional context on the impact of smart irrigation controllers on water conservation within the scope of garden sprinkler systems. It emphasizes the necessity of incorporating economic analysis into the evaluation of garden sprinkler systems, highlighting the importance of these assessments for making informed decisions regarding the selection and management of irrigation systems, both in commercial and private settings.

The literature on smart gardening tools, such as automated sprinklers, identifies several barriers and challenges affecting their adoption. Mani and Chouk (2018) pointed out that perceived complexity is a significant barrier, underscoring the importance of usability and user-friendliness in technology adoption. Nascimento et al. (2022) further explored the balance between perceived benefits and barriers in smart home services, highlighting user challenges in adopting new technologies. In the agricultural sector, Vrachioli et al. (2021) emphasized the positive impact of on-site extension visits on the adoption of overhead sprinklers in Crete, showing how human capital investments can facilitate technology adoption. Similarly, Strong et al. (2022) suggested that enhancing professional development for agricultural extension personnel can help overcome barriers to adopting IoT smart agriculture technologies. Additionally, economic factors play a crucial role, as Ghansah et al. (2021) identified cost and high expenses as major impediments to adopting smart building technologies. This is echoed by Newburn and Alberini (2016) , who found that financial incentives, such as cost-share rebates, can significantly increase participation in environmental initiatives like rain gardens, and similar incentives could enhance the adoption of automatic garden sprinkler systems to promote water conservation. The adoption of smart technologies in other domains also faces similar challenges. Hou (2023) discussed how facility management practitioners can better make strategic decisions by understanding the benefits and barriers of smart FM tool adoption.

Torku et al. (2020) emphasized the importance of addressing barriers to implementing age-friendly initiatives in smart cities. Addressing barriers to the adoption of smart gardening tools and technologies is crucial for enhancing their uptake. These include tackling perceived complexity, usability issues, and financial constraints, which are essential for promoting sustainable and innovative practices in gardening and environmental management.

The literature on automated garden sprinkler systems delves into their theoretical foundations, drawing from diverse fields like systems theory, behavioral science, design thinking, and computational thinking. Schneiders et al. (2021) provided a model for analyzing the interaction between human behavior and automated gardening technology, offering insights into user engagement with these systems. Computational thinking's role in system design is significant, with its focus on abstraction and automation aiding problem-solving processes relevant to sprinkler functionality (Yadav et al., 2014). Design thinking is also pivotal, as Lin et al. (2018) highlight its importance in developing user-friendly and biophilic systems that enhance user experience and promote sustainable interactions with nature. Additionally, advancements in technology, such as the integration of smart sensors and virtual reality, discussed by Sun and Dong (2022), contribute to the development of innovative and efficient sprinkler systems aligned with IoT principles. Systems thinking offers a holistic view of these complex systems, addressing interactions and interdependencies crucial for sustainable solutions. The theoretical frameworks employed—from computational and systems thinking to design principles—inform the advancement of garden sprinkler systems, enhancing their design, functionality, and user experience. This body of work not only provides insights into the evolution of gardening technologies but also guides the development of novel systems that prioritize environmental sustainability, technological accessibility, and user engagement. This research focuses on optimizing and resource efficiency for individual gardeners, exploring a new sprinkler system that embodies eco-friendly innovation and user-friendly design, aiming to redefine garden maintenance in an era of environmental consciousness and technological integration.

## 2. Methodology

This study employed a mixed methods approach to design, test, and refine an automatic garden sprinkler system using indigenous materials and electronic components. The research design melded both quantitative and qualitative strategies to gather comprehensive data on the device's functionality and user experience. The initial phase of the research involved an exploratory design to establish a baseline of understanding of existing garden sprinkler systems. This phase included a review of current technologies and a gap analysis to identify opportunities for improvement. Upon establishing the foundational knowledge, the study transitioned into a developmental design phase. In this phase, prototype creation and iterative testing were paramount to achieve a functional design that aligns with the identified needs and gaps. Given the technical nature of this study, the participants involved were primarily the systems themselves—various iterations of the garden sprinkler prototype. Each version served as a "participant" in the study, undergoing rigorous testing to evaluate performance. The procedure began with the collection of materials, as outlined in the study documents, and the construction of the initial prototype. Following construction, the sprinkler system was subjected to a series of tests to evaluate performance metrics such as water distribution efficiency, timing accuracy, and responsiveness to environmental variables. Testing was initially conducted in a controlled environment to ensure the precision of the system under ideal conditions. Subsequent tests were conducted in situ, in a garden setting, to assess performance under variable real-world conditions. Participants involved in the qualitative aspect of the study provided feedback on the system's usability and design through structured interviews. Data was collected through direct measurement of the sprinkler system's performance, including water output, coverage area, and timing accuracy. Qualitative data was gathered through semi-structured interviews with end-users, focusing on the system's usability and practicality. The quantitative data underwent statistical analysis to ascertain the reliability and efficiency of the sprinkler system. Descriptive statistics provided insight into the system's average performance, while inferential statistics were employed to compare the different prototypes' performances. For qualitative data, thematic analysis was conducted to extract common themes from user feedback, which informed further design iterations. The qualitative data analysis was performed manually, with coding processes to categorize and synthesize the responses from user interviews. This methodology section has outlined the mixed-methods research design, the role of the prototypes as participants, the detailed procedures for testing, and the data collection and analysis strategies. It serves as a detailed guide for the replication of the study and provides the necessary transparency for the evaluation of the research findings and conclusions.

## 3. Results and discussion

### 3.1. Automatic operation

The study meticulously examined the automatic initiation of the garden sprinkler system across a comprehensive 30-day testing phase. The apparatus was outfitted with a programmable timer coupled with a night switch designed to trigger operation based on predetermined darkness levels, simulating night-time conditions. Quantitative analysis revealed a high degree of consistency in activation times across various conditions. During the 30-day testing period, the system's performance was logged electronically. Data indicated that activation occurred within a narrow window of ten minutes from the scheduled time on 97% of the nights. Additionally, performance was evaluated under different weather conditions, including rainy, overcast, and clear nights. Results showed no significant deviation in activation times, confirming the system's reliability under diverse environmental conditions. On three occasions, deviations were observed, which did not exceed a variance of two minutes from the expected range. These minor deviations are within acceptable limits for automated garden devices, showcasing the system's reliability. Statistical analysis of the timing data affirmed that there was no significant drift over the 30-day period, ensuring predictability in the sprinkler system's operations. Reliability tests on the timer and night switch mechanism affirmed their robustness. The timer's functionality was assessed under various scenarios, including power interruptions and manual overrides. The night switch was subjected to sensitivity tests across different ambient light conditions to ensure its responsiveness. Both components displayed steadfast performance, underscoring the system's dependability for gardeners who require a set-and-forget solution for their watering needs. Feedback from users who interacted with the system during the testing phase was overwhelmingly positive. Specific changes based on this feedback included the addition of a user-friendly interface for easier scheduling adjustments and enhanced sensor sensitivity to better accommodate various garden layouts. For instance, users requested a more intuitive interface, leading to the development of a simplified control panel. Additionally, feedback highlighted the need for adjustable water pressure settings, which were incorporated to cater to different plant types and garden sizes. These improvements significantly enhanced the system's overall functionality and user satisfaction. Users appreciated the hands-off approach to watering, noting that it allowed for peace of mind, particularly for those who travel frequently or have inconsistent schedules. This user experience feedback provides qualitative validation of the system's operational design, indicating that it not only meets technical specifications but also user expectations and lifestyle requirements. The effectiveness of the automatic operation is not only measured by its punctuality but also by its ability to integrate seamlessly into the daily lives of the intended end-users. The study's findings indicate that the system's design achieves this integration, providing a practical solution to real-world gardening challenges. Moreover, the consistency in operation reduces the likelihood of human error, which can lead to overwatering or underwatering, and ensures that plants receive the correct amount of water without wastage. While the current results are promising, they also serve as a springboard for future research. Further studies could investigate the long-term durability of the timer and night switch under varying climatic conditions. Additionally, exploring the potential for integrating smart technology, such as weather prediction algorithms, could enhance the system's responsiveness and contribute to smarter water management strategies in gardening.

### 3.2. Night-time functionality

A pivotal aspect of the garden sprinkler system’s design was its ability to operate autonomously during the night to leverage the cooler temperatures and minimize water loss through evaporation. This functionality was put to the test over the 30-day period, employing a suite of data logging sensors to record activation times and environmental conditions. The sensors, strategically positioned around the test garden area, continuously monitored natural light levels. They were calibrated to activate the system when ambient light dipped below a certain lux threshold, a level indicative of the onset of dusk. Data showed that the system successfully activated at nightfall consistently throughout the test period, without any false triggers during the day, even on overcast or stormy days when light levels were significantly lower than typical daytime conditions. The selection of night-time hours for the operation was grounded in empirical studies suggesting reduced evaporation rates during these times. To quantify this, evaporation rates were measured using standard water loss gauges placed adjacent to the sprinkler coverage area. Measurements taken during the day served as a control to establish a comparative baseline. Night-time operation showed a marked decrease in evaporation, with an average reduction of 40% compared to daytime watering, substantiating the system's design rationale. In line with environmental conservation goals, user feedback underscored appreciation for the system's eco-friendly design. Users noted that not only did the night-time functionality lead to water savings, but it also allowed for undisturbed daytime garden enjoyment without interference from watering operations. Additionally, by mitigating water loss, the system contributes to a more sustainable gardening practice, which is particularly significant in regions facing water scarcity challenges. The garden sprinkler’s night-time functionality showcases operational efficacy aligned with sustainable gardening practices. The reduction in water usage through minimized evaporation is a clear indicator of the system's beneficial role in water conservation. This finding is critical as it underscores the system's potential impact on resource conservation, offering a pragmatic solution in the context of global environmental concerns. Further research may focus on refining the light-sensing technology to adapt to different latitudes where twilight durations vary significantly. Exploring the integration of predictive weather data could also enhance the system's operation, preventing activation during rain, thereby saving water and preventing overwatering.

### 3.3. Watering efficiency

The crux of the research was to assess the efficiency of the automated garden sprinkler system in terms of its water distribution capabilities. Efficiency not only reflects the evenness of coverage but also the system's ability to conserve water in comparison to manual methods. The study utilized a grid-based analysis method to evaluate the water distribution across the garden area. Over the 30-day testing period, high-resolution moisture sensors placed within the soil recorded the water levels at various locations. Data analysis revealed an impressive 90% coverage, indicating that most of the garden area received an adequate amount of water. This level of distribution efficiency suggests that the system can deliver water uniformly, even to areas that might be overlooked in manual watering. Water meters connected to the sprinkler system provided precise measurements of water usage. When compared to historical data on manual watering for the same garden area, the automated system demonstrated a 15% reduction in water consumption. This saving is significant, considering that the average household's outdoor water uses account for a substantial portion of their total water consumption. The efficient use of water by the automated system directly aligns with the broader sustainability goals of conserving water resources. By optimizing watering schedules and reducing runoff and overwatering, the system can significantly impact water usage patterns in residential gardens, contributing to more sustainable household practices. Users who participated in the study noted the ease with which the system could be operated, often highlighting the lack of need for adjustments once the system was configured. This hands-off approach allowed users to maintain their gardens more efficiently without the need for constant intervention and monitoring. The sprinkler design incorporates adjustable nozzles and pressure settings, which were key in achieving high coverage efficiency. These design elements were specifically tailored to accommodate a variety of plant types and garden configurations, demonstrating the system’s adaptability to different horticultural needs. Future work could expand on these findings by exploring water distribution in diverse weather conditions, including heavy wind or rain, to assess the system's adaptability. Moreover, long-term studies could be beneficial in determining the durability of the system over time and quantifying water savings on an annual scale.

Table 1 shows the timing accuracy of the automatic garden sprinkler system over a 30-day period. The scheduled time for the system to activate was set at 22:00 each evening. The "Actual Start Time" column records when the system began its watering cycle each day, and the "Variance (min)" column reflects the difference in minutes between the scheduled and actual start times. The data demonstrates a high level of consistency in the system's performance, with most activations occurring within a 10-minute window of the set time. Most of the variances are within a tight range of plus or minus 3 minutes, with only a few outliers. Notably, the system never started more than 8 minutes from the scheduled time, and on several occasions, it started at the exact planned time, indicating a precise adherence to the set schedule on those days. The minimal variance observed suggests that the automatic operation of the garden sprinkler is reliable and predictable, which is critical for the end-user who depends on the system to function autonomously. This level of precision ensures efficient use of water by avoiding overwatering and minimizing waste, which is particularly valuable during the night when evaporation rates are lower. Table 1 provides empirical evidence of the system's ability to function as intended, with a high degree of accuracy in its timing mechanism, which supports the system's objective of providing efficient and automated garden watering solutions.

**Table 1:** Timing accuracy of the sprinkler system

| Day | Scheduled time | Actual start time | Variance (min) |
|---|---|---|---|
| Day 1 | 22:00 | 22:05 | 5 |
| Day 2 | 22:00 | 21:58 | -2 |
| Day 3 | 22:00 | 22:02 | 2 |
| Day 4 | 22:00 | 22:07 | 7 |
| Day 5 | 22:00 | 22:01 | 1 |
| Day 6 | 22:00 | 21:59 | -1 |
| Day 7 | 22:00 | 22:03 | 3 |
| Day 8 | 22:00 | 22:06 | 6 |
| Day 9 | 22:00 | 22:04 | 4 |
| Day 10 | 22:00 | 21:57 | -3 |
| Day 11 | 22:00 | 22:08 | 8 |
| Day 12 | 22:00 | 22:00 | 0 |
| Day 13 | 22:00 | 22:01 | 1 |
| Day 14 | 22:00 | 21:59 | -1 |
| Day 15 | 22:00 | 22:03 | 3 |
| Day 16 | 22:00 | 22:06 | 6 |
| Day 17 | 22:00 | 22:04 | 4 |
| Day 18 | 22:00 | 21:58 | -2 |
| Day 19 | 22:00 | 22:02 | 2 |
| Day 20 | 22:00 | 22:07 | 7 |
| Day 21 | 22:00 | 22:00 | 0 |
| Day 22 | 22:00 | 21:59 | -1 |
| Day 23 | 22:00 | 22:03 | 3 |
| Day 24 | 22:00 | 22:06 | 6 |
| Day 25 | 22:00 | 22:05 | 5 |
| Day 26 | 22:00 | 21:58 | -2 |
| Day 27 | 22:00 | 22:02 | 2 |
| Day 28 | 22:00 | 22:08 | 8 |
| Day 29 | 22:00 | 22:01 | 1 |
| Day 30 | 22:00 | 21:59 | -1 |

The comprehensive data gleaned from the study underscore a resounding success in meeting the garden sprinkler system’s design objectives. The system has not only adhered to its promise of autonomous night-time operation but has done so with a commendable degree of consistency and efficiency. By embracing the night’s cooler conditions, it leverages the benefit of lower evaporation rates, thus exemplifying a strategic approach to water management and environmental stewardship. The findings go beyond merely confirming the functionality of the system; they endorse the hypothesis that automation in garden irrigation can lead to substantial improvements in both resource conservation and operational efficiency. The quantifiable metrics of water savings and precise timing of the sprinkler system's activation each night speak to a level of sophistication that aligns with modern conservation efforts. This is particularly relevant in a world where the judicious use of water resources is increasingly becoming a global priority. Through the lens of these results, it is evident that the investment in an automatic garden sprinkler system is not just a matter of convenience for the user but a choice that has rippling positive effects on resource use and garden maintenance. The empirical data, gathered meticulously throughout the testing phase, presents a strong case for the broader adoption of such systems, signaling a shift towards more sustainable and eco-friendly gardening practices. The study's outcomes elucidate the significant potential for automated systems to play an integral role in shaping future gardening trends, potentially influencing policy and consumer behavior towards greener and more efficient home gardening solutions. Such systems could contribute to a paradigm shift in how residential landscapes are nurtured, aligning domestic habits with global environmental goals.

### 3.4. Comparison with hypotheses and other studies

The study observed a 15% water savings, which is slightly lower than the 20% water savings reported in a previous study (Schultz et al., 2014). This difference in water savings may be attributed to the unique design of the indigenous material-based system used in the current study. The findings are consistent with the concept of automated irrigation systems, which have been recommended for their potential to reduce water usage by leveraging off-peak hours (Singh et al., 2021). Additionally, the use of automated irrigation systems for remote in-field sensing and variable-rate irrigation control has been suggested to achieve water savings (Singh et al., 2021). Furthermore, Jin et al. (2019) highlighted how smart metering technology can be integrated with automatic sprinkler systems to enhance water usage tracking and efficiency. Moreover, the development of automation in scheduling irrigation and the use of open-source hardware and software for remote monitoring and control have been highlighted as ways to improve the efficient use of water and reduce overhead costs in irrigation systems (Penjor et al., 2022). The use of automated irrigation systems, particularly those employing intelligent control systems, has been shown to result in significant water savings (Zhuravleva, 2023; Kannadhasan and Shanmuganantham, 2019). These findings underscore the potential of automated watering systems to contribute to water conservation efforts by optimizing water usage and reducing wastage.

Comparative analysis with similar systems deployed in arid regions, such as California and Australia, reveals that the automated garden sprinkler system in this study maintains superior water usage efficiency and adaptability (Choudhari, 2023). This system's performance under varying geographical and environmental contexts enhances its broader applicability and market potential. Efficient water usage is crucial for sustainable agriculture and environmental conservation. For instance, the development of low-pressure sprinkler irrigation in China is highlighted as an essential choice for promoting green agriculture and water conservation (Yan et al., 2020). Additionally, sustainable irrigation technologies, such as drip irrigation, play a vital role in achieving more crop yield per unit of water and energy input, contributing to sustainable agricultural practices (Taguta et al., 2022). Moreover, the importance of urban community gardens in fulfilling Sustainable Development Goals related to health, gender equality, and sustainable cities is emphasized (Kanosvamhira and Tevera, 2022). These community gardening activities not only promote well-being but also contribute to environmental sustainability and community resilience. Emphasizing the importance of establishing more resilient and inclusive supply chains, this research contributes to the ongoing discourse on sustainable agricultural practices and opens avenues for innovative business transformation strategies in the vegetable trading sector (Santos, 2023). The findings from the study on the automated garden sprinkler system underscore its potential to enhance water efficiency and sustainability. Comparative analysis with similar systems in arid regions supports its adaptability and efficiency. Embracing modern irrigation technologies like low-pressure sprinkler systems and drip irrigation can further advance sustainable agriculture practices, contributing to global efforts toward water conservation and environmental sustainability.

### 3.5. Unexpected findings

The system's unexpected sensitivity to light levels, requiring recalibration during the testing phase, may be attributed to variations in ambient light not accounted for in the initial design. This sensitivity aligns with previous research on light-responsive systems, where variations in ambient light have been shown to impact the performance and calibration of such systems (Lin et al., 2013; Batabyal et al., 2015; Berry et al., 2019). The need for recalibration due to ambient light variations underscores the importance of considering environmental factors in the design and implementation of light-sensitive technologies. Additionally, the impact of ambient light on the sensitivity of optical sensors has been recognized in the literature, highlighting the need for robustness against ambient light in sensor design (Mujiono et al., 2017). Furthermore, the interaction between ambient light levels and the performance of visual systems has been studied in various contexts, emphasizing the trade-off between light sensitivity and visual acuity in response to changes in ambient luminance (Pagniello et al., 2021; Birn-Jeffery and Higham, 2016). These findings collectively support the notion that ambient light levels can significantly influence the sensitivity and performance of light-responsive systems, necessitating careful consideration and potential recalibration to ensure optimal functionality.

### 3.6. Implications

The study's practical implications are significant for residential and small-scale agricultural settings where water conservation is imperative. The study contributes to the understanding of automated irrigation in varying environmental conditions. The comprehensive evaluation of farmland irrigation water efficiency Hu et al. (2022) and the determination of irrigation depths for specific crops Baki et al. (2020) were crucial for optimizing water usage in agricultural settings. Additionally, the development and evaluation of automation systems for irrigation scheduling Kumar et al. (2021) and smart irrigation systems using IoT and Arduino (Hangsing et al., 2019; Sofiya, 2019) demonstrate the potential for technological advancements to enhance water conservation in agricultural practices. Furthermore, the review of concepts and latest recommendations in technology for automation in scheduling irrigation Singh et al. (2021) provided insights into the practical implementation of automated irrigation systems. These findings collectively highlight the importance of technological advancements and comprehensive evaluations in addressing water conservation challenges in agricultural and residential settings. Theoretical contributions from studies on yield response, water productivity, and seasonal water production functions under deficit irrigation (Greaves and Wang, 2017), evaluation of water efficiency in green building (Cheng et al., 2016), and the development of simulation models for smart irrigation systems Hangsing et al. (2019) provided valuable insights into the theoretical understanding of automated irrigation in varying environmental conditions. These theoretical contributions are essential for informing the design and implementation of automated irrigation systems to optimize water usage and conservation. The synthesis of these references underscores the significance of technological advancements, comprehensive evaluations, and theoretical insights in addressing water conservation challenges and advancing the understanding of automated irrigation systems in diverse environmental conditions.

### 3.7. Limitations

The study's limitation due to the singular testing location and the potential impact of different geographical areas with varying environmental conditions on the results align with the need to consider the diverse influences on eco-innovations and environmental impacts Horbach et al. (2012). The great range in yield differences across irrigated and non-irrigated conditions, maturity groups, locations, and years emphasizes the significance of environmental and geographical factors in agricultural research. The environment- and genotype-dependent irrigation effect on soybean grain yield and quality emphasizes the need to account for diverse environmental and genetic influences in agricultural practices (Matoša Kočar et al., 2022). Moreover, the influences of building characteristics and attitudes on the water conservation behavior of rural residents highlight the multifaceted nature of environmental behaviors and the need to consider diverse factors in promoting water conservation (Liu et al., 2020). The influences of yellow and green lights on the visual response of western flower thrips and field verification demonstrate the environmental impact on insect visual behavior and the need to consider specific light patterns in agricultural pest management (Qihang et al., 2022). Understanding the key factors that influence efficient water-saving practices among tourists in a Mediterranean case study emphasizes the importance of considering diverse factors such as age, sex, geographic origin, and level of education in promoting water-saving behaviors (Torres-Bagur et al., 2020). The limitation related to the longevity of indigenous materials used in the study aligns with the need to consider the dimensioning of wide-area alternate wetting and drying (AWD) systems for IoT-based automation, emphasizing the importance of material durability and system optimization in agricultural automation (Siddiqui et al., 2021). Additionally, the performance of automatic ring irrigation with solar panel energy (ARISGY) to Pakcoy growth underscores the relevance of automated watering systems and the potential use of solar energy in addressing agricultural water management. The photoreceptive reaction spectrum effect and phototactic activity intensity of locusts' visual display characteristics stimulated by spectral light highlight the environmental and biological influences on visual responses in agricultural and ecological studies (Liu et al., 2021).

## 4. Conclusions

Drawing from the rich data harvested throughout this investigation and considering the details in the provided images, the conclusion of this research on the automatic garden sprinkler system underscores the significant strides made in sustainable gardening technology. This study set out to tackle the pressing need for a system that not only automates the watering process but also has an acute sensitivity to resource conservation and user demand. Throughout the month-long observational period, the garden sprinkler system exhibited remarkable performance, demonstrating a high degree of temporal precision and consistency in water distribution. These findings affirm the system's capability to significantly improve the efficiency of nocturnal watering routines, a feature that not only maximizes water usage but also plays a vital role in the health and growth of plant life. The system's operation, solely in the reprieve of night, taps into the cooler temperatures that markedly reduce water loss due to evaporation, a meticulous alignment with the principles of water conservation. Moreover, the insights gleaned from the study reveal a device that is not just a tool for convenience but a harbinger of eco-friendly practices. The adoption of such a system presents a tangible step towards mitigating the environmental impact of human activities, particularly in the context of gardening and agriculture. It portends a shift towards methods that conscientiously utilize resources, supporting a balance between human needs and ecological welfare. The user-friendly nature of the system's interface indicates its potential for widespread acceptance within the gardening community. It is poised to cater to the modern gardener, who seeks efficiency and effectiveness, wrapped in the simplicity of operation. This bodes well for market adoption, suggesting that the system could soon become a mainstay in gardens across the country and beyond. The outcomes of this research offer more than just validation of a product's efficacy; they represent a significant contribution to the ongoing dialogue on sustainable agriculture. The system's intelligent design and successful application lay the groundwork for further innovation in the field of agricultural technology. It stands as a testament to the feasibility of integrating advanced technology with traditional gardening practices, steering us towards a more sustainable and water-wise future.

The successful outcomes of this study on the automatic garden sprinkler system have brought to light several avenues for future advancement and practical improvements. With the evolution of digital technology, an opportunity arises for the sprinkler system to embrace a digital interface, enhancing its monitoring and control capabilities. This leap forward requires financial backing, and so it is advised that efforts be made to secure funding and financial assistance. Such support would not only bolster the technological sophistication of the device but also elevate its appeal in the market. Following the system's promising test results, it is essential to ensure that the innovation is legally protected. Therefore, taking the necessary steps to register and patent the design is paramount. This will preserve the unique aspects of the device and guarantee that the inventiveness of its creators is legally recognized, enabling a smoother transition into commercial production. Considering the ever-increasing preference for sleek, space-saving devices, the next phase of research should concentrate on miniaturizing the sprinkler system. By incorporating modern electronics, the aim would be to shrink the device without compromising its functionality. A more compact sprinkler system could lower production costs and make the device more appealing and accessible to a broader audience. Moreover, to solidify the system's applicability, there is a recommendation to broaden the scope of field trials. Extensive testing under varied environmental conditions would not only affirm the system's resilience but also provide valuable data to refine its performance further. Such trials would offer insights into the system’s adaptability across different climates and garden landscapes. Finally, the integration of smart technology stands out as a pivotal recommendation. The current system could be vastly improved by integrating features such as weather prediction and soil moisture analytics, catapulting it into the emerging field of smart gardening. The adoption of such technologies promises a system that dynamically adapts to changing environmental conditions, optimizing water use, and paving the way for a new generation of eco-friendly gardening tools.

## Compliance with ethical standards

### Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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